Naval Research Laboratory

Washington, DC 20375-5320

NRL/MR/6440-95-7658

Constitutive Modeling of Air and Water Saturated Sand for Shock Propagation Modeling

Workshop Summary and Recommendations

MARK H. EMERY

Center for Computational Physics Developments
Laboratory for Computational Physics and Fluid Dynamics

PHILIP J. VALENT
L. DALE BIBEE

Marine Geosciences Division
Stennis Space Center, MS

April 7, 1995

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 7, 1995	September 20-21, 1994

4. TITLE AND SUBTITLE

Constitutive Modeling of Air and Water Saturated Sand for Shock Propagation Modeling
Workshop Summary and Recommendations

5. FUNDING NUMBERS

PE - 62435N

6. AUTHOR(S)

Mark H. Emery, Philip J. Valent,* and L. Dale Bibee,*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

Naval Research Laboratory
Stennis Space Center, MS 39529

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/6440--95-7658

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Same

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

*Marine Geosciences Division, Naval Research Laboratory, Stennis Space Center, MS 39529

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The mine countermeasure research program is an Office of Naval Research program that addresses the physical characterization and modeling of the surf zone environment, explosive shock propagation and mitigation in this environment, and the means to improve the performance prediction of mine countermeasure efforts in the surf zone. This report summarizes the results of the *Workshop on Constitutive Modeling of Air and Water Saturated Sand for Shock Propagation Modeling* sponsored by the Naval Research Laboratory. The objectives of this workshop were to appraise the present state of knowledge with respect to the characterization of the air and water saturated sandy medium, the experimental evidence for shock mitigation and propagation in this medium, the present constitutive modeling capabilities, and to develop a focused research effort to address the complex physics issues related to this task. Participants discussed issues associated with mine countermeasure systems including shock wave propagation in sandy sediments with water and free-air pore fluid, measurement of the mechanical properties of both dry and partially saturated sand, hydrodynamic modeling of this environment, and continuum and micromechanical aspects of constitutive models.

14. SUBJECT TERMS

Shock wave propagation
Air and water saturated sandy medium
Mine countermeasures systems
Constitutive modeling

15. NUMBER OF PAGES

16

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

I. FORWARD

The *Workshop on Constitutive Modeling of Air and Water Saturated Sand for Shock Propagation Modeling* was held on September 20 - 21, 1994, at the Naval Research Laboratory, Washington, DC. The workshop was sponsored by the Naval Research Laboratory and was chaired by Mark H. Emery, Code 6440, and Philip J. Valent, Code 7401. The objectives of this workshop were to appraise the present state of knowledge with respect to the characterization of the air and water saturated sandy medium, the experimental evidence for shock mitigation and propagation in this medium, the present constitutive modeling capabilities, and to develop a focused research effort to address the complex physics issues related to this task. Twenty-five scientists/engineers attended the workshop with participation from NRL, NSWC, ONR, DNA, the university community, and private industry. Participants discussed issues associated with mine countermeasure systems including shock wave propagation in sandy sediments with water and free-air pore fluid, measurement of the mechanical properties of both dry and partially saturated sand, hydrodynamic modeling of this environment, and continuum and micromechanical aspects of consititutive models. Subsequent sections provide the workshop announcement, planned agenda, summaries of the participants' presentations, and findings and recommendations (incorporating information shared in open discussions with the participants) which includes the opinions of the workshop chairs (Emery and Valent) which may differ from the opinions of the workshop participants.

This workshop serves only to initiate the scientific and technological (S&T) dialogue addressing the research and development requirements of the Navy and Marine Corp. From this beginning it is anticipated that some focussed set of S&T programs will be formulated. These will involve a broader spectrum of scientists and engineers whose expertise is required to address the relevant problems. The need for research in this area is compelling and we seek to lead that research in directions offering the most promise for the DoD while advancing the state-of-the-art benefiting the nation as a whole.

Eric O. Hartwig
Associate Director of Research
Ocean and Atmospheric Science
and Technology
Naval Research Laboratory

Manuscript approved December 12, 1994.

II. WORKSHOP ANNOUNCEMENT

WORKSHOP ON CONSTITUTIVE MODELING OF AIR AND WATER SATURATED SAND FOR SHOCK WAVE PROPAGATION PREDICTION

September 20 - 22, 1994

The US Naval Research Laboratory
Washington, DC 20375-5000

Workshop Sponsored
by
Naval Research Laboratory and Office of Naval Research

Background and Aim:

The US Navy is in urgent need of a self-consistent numerical capability for modeling explosion and shock effects in surfzone seafloor sediments, primarily sands, with seawater and free-air pore fluid. One of the most complex tasks in this effort is the development of accurate, efficient, and physics based constitutive models for gassy sediments in and near surfzone environments. The gassy sediment environment is a complex microscale medium characterised by sediment structure parameters (porosity; permeability; tortuosity; grain size, shape, mineralogy, and packing; shear strength; anisotropy), gas parameters (bubble size, shape, orientation, and distribution; gas volume), and fluid parameters (distribution; water volume; compressibility). Improved constitutive models are needed for progress in performance prediction of mine countermeasure efforts.

The aims of this workshop are to appraise the present state of knowledge with respect to the characterization of this medium, the experimental evidence for shock mitigation and propagation in this medium, the present constitutive modeling capabilities, and to develop a focused research effort to address the complex physics issues related to this task.

Proposed Topics:

Characterization of the medium (in support of shock propagation modeling)

Presentations will focus on detailed descriptions of the gassy sediment environment, emphasizing sand sediments, the degree of variability of the sediment, gas, and fluid parameters, the relative physical importance of these variables, and the resolution of the techniques for measurement of the parameters for input for the constitutive models.

Acoustic and shock wave propagation

This topic will focus on the availability, resolution, and accuracy of experimental results (both in situ and laboratory) pertaining to acoustic and shock wave propagation in this medium. The relative roles of the physical variables (and their sensitivity) that influence the propagation characteristics will be emphasized.

Constitutive modeling

Emphasis will be placed on clarifying the present modeling capabilities, the physics that is presently being modeled, deficiencies in the present modeling capabilities, and potential solutions to these problems. Topics of interest include microscale modeling, macroscale modeling, and the synthesis of macroscale models from microscale models.

III. AGENDA

Workshop on Constitutive Modeling
of Air and Water Saturated Sand
for Shock Propagation Prediction

September 20-21, 1994

The US Naval Research Laboratory
4555 Overlook Dr SW
Washington, DC 20375

Tuesday, September 20, 1994

8:30 AM	Registration and Coffee
9:30 AM	M. Emery (NRL), *Welcome and Opening Remarks*
9:45 AM	H. Chen (NSWC/WO), *Overview of the Mine Counter Measure Problem*
10:15 AM	R. Barsoum (ONR), *Constitutive Modeling of Sands/Soils*
10:45 AM	P. Valent (NRL/SCC), *Characterization of the Medium*
11:15 AM	Discussion Session
12:00 PM	Lunch
1:30 PM	R. Dick (Univ MD), *Hopkinson Bar and Explosive Studies of Wet and Partially Saturated Sands*
2:00 PM	D. Chitty (ARA, Inc.), *Field and Laboratory Investigations of Wave Propagation in Saturated Sand*
2:30 PM	R. Walker (ARA, Inc.), *Ground Shock Attenuation in Three Phase Earth Materials*
3:00 PM	Coffee Break
3:30 PM	R. Pandey (Univ. S. Miss.), *A Microscopic Simulation Approach to Fluid Flow Through Porous Media*
4:00 PM	Summary and Discussion

Wednesday, September 21, 1994

8:30 AM	Registration and Coffee
9:30 AM	A. Shukla (Univ RI), *Experimental and Numerical Studies of Wave Propagation in Granular Materials Subjected to Explosive Loadings*
10:00 AM	D. Flippen (NRL), *Methods of Synthesizing Macroscale Models From Microscale Models for Composites with Planned Adaptions to Sand*
10:30 AM	D. Zhang (Johns Hopkins Univ), *Ensemble Phase Averaged Equations and Constitutive Relations for Dispersive Flows*
11:00 AM	D. Peric' (Univ. Co-Denver), *Discontinuous Bifurcations in Partially Saturated Soils Under Undrained Conditions*
11:30 AM	R. England (TRT, Inc), *Review of Previous DNA Water Shock Program*
12:00 PM	Lunch
1:30 PM -	Summary and Discussion (Open Workshop)

In all three topics, the focus of the workshop will be on the physical properties of this complex medium, assessment of the present state of the art in modeling those properties, and potential improvements to existing models or development of new constitutive models.

Format:

The format of the workshop will consist of two full days of thirty-minute presentations (plus discussion time) by workshop participants. The agenda will be separated into the three general topics discussed above. There will be a thirty-minute discussion period at the end of each general session. In addition, one-half of the third day will be a roundtable, brainstorming session for all participants which will review the present state of the art, assess the physics issues, their relevance, the means to measure them and model them, analyze the present constitutive modeling capabilities, and develop a research agenda (both experimental and numerical) to address the physics issues in order to accelerate the progress of performance prediction of mine countermeasure efforts.

IV. SUMMARY OF PRESENTATIONS

Chen and Barsoum provided an overview of the mine countermeasure problem from the 6.2 and 6.1 perspective respectively. The concept entails the projection of an explosive net onto the surf zone and subsequent detonation of the net to clear a safe path for landing craft. This procedure is simple in concept but complex in execution. To predict performance of such a system requires the ability to predict shock propagation through wet sands that are partially filled with gas. The performance of this system is being estimated by field tests in test pond sites and by computational simulations as there can be no tests of the explosive array on real beaches based on current environmental policies. In addition, the distributed explosives require high energy and low charge diameter. Chen presented results from a two dimensional, P_α - based CTH simulation of a charge array on a sand surface under water. He also discussed, conceptually, a smooth particle hydro (SPH) model as a micromechanical approach to modeling the sand. Barsoum discussed several 6.1 endeavors - split-Hopkinson bar experiments, micromechanically based constitutive models, and double asymptotic approximations for wet sand/mine interaction. Valent discussed several aspects of the characterization of the medium such as variability of grain size and saturation levels.

Dick presented results from dynamic loading by the split-Hopkinson pressure bar on dry and partially saturated Big Black and Eglin sands. Results were that dry sand crushes readily and void collapse was incomplete for the stresses achieved in these tests. For wet sands, void collapse required at least 100 MPa and 20 msec before significant stresses could be transmitted. Additional measurements of pressure in wet sand as a function of range from the explosive charge indicated that the stress at 50 mm range (240 MPa) was reduced to 100 MPa at 140 mm range. Chitty and Walker presented field, laboratory, and computational investigations of wave propagation in saturated sands. The laboratory testing focused on hydrostatic compression, uniaxial strain, and triaxial compression tests to measure the mechanical properties of sands to support their effective stress modeling. Measurements were made of the pore fluid flow rates through various sands and various means to measure saturation levels in situ were discussed. They concluded that the multiphase effective stress model reproduced the basic physics of the groundshock, detailed skeleton models were needed for accurate late time simulations, and relative flow models were needed to calculate late time fluid redistribution. England compared measured water pressure and sand stress histories for a scaled 1000 lb burst buried 25 ft in sand under 50 ft of water with results calculated with an effective stress hydrodynamic model. Predicted and measured peak water pressures, as a function of range, agreed to within 30% for both fully saturated and partially saturated sand bottoms. He concluded that gas filled porosity is the dominant material parameter controlling shock attenuation.

The micromechanical models were presented by Pandy, Shukla, Barsoum, and Peric'. Pandy presented results from a percolation-based computer model to study the permeability of fluid flow through porous media and results from a direct simulation Monte Carlo model to study shock propagation through porous media. The permeability showed a nonmonotonic dependence on the fluid concentration and on the driving bias. The

shock propagates in a drift like fashion under high porosity; the shock front damps out very quickly with low porosity. Shukla discussed experimental and numerical studies on stress wave propagation through small polycarbanate disks. Results showed no transverse propagation of the stress waves through linear arrays of disks under load. Propagation through arrays of randomly oriented disks of random size was dependent on the structure of the material fabric. When water was placed between the disks, the magnitude of the contact load was severely attenuated as a function of propagation distance. The results were compared with a discrete element model. Barsoum discussed a microplane approach that included strain rate effects based on three phase micromechanical behavior. Peric' discussed the importance of the shear band instability in soil mechanics and a bifurcation in the pore pressure which sets limits in the range of validity for the expressions for the rate of displacement.

The synthesis of macroscale constitutive relations from microscale constitutive relations was discussed by Flippen and Zhang. Flippen discussed the Condensation Model Reduction (CMR) approach which can be directly coupled to current finite element models. This model has achieved some success in modeling laminates and ceramics. He discussed implementing a macroscale semi-discrete constitutive operator synthesis for saturated sediments. Zhang employed an ensemble phase averaged method to develop constitutive laws for FEM and CFD codes. He argued that this method provides a link between micromechanics and the macroscopic model while retaining the physics of the phase interaction.

V. COMMENTS ON PRESENTATIONS

It is clear that, to lowest order, the gas content is the dominant parameter controlling shock attenuation in the surf zone environment. Even a minute amount of air drastically alters the pore pressure response in multiphase porous materials. Air content as small as 1% can reduce the shock speed by factors of 3 - 4, and reduce the shock amplitude by factors of 20 or more. This is borne out by both experiment and numerical simulation. It is also clear that there is no accepted method to accurately, and rapidly, measure the gas content in partially saturated sands/soils either in situ or under laboratory controlled conditions.

Several of the computational hydrodynamic models incorporated continuum models for the partially saturated sand environment. These included the effective stress model, the P_α model, and the multiphase effective stress model. The predictions from the effective stress model agreed reasonably well with experimental results (to within 30%) under conditions of relatively large loads stemming from deeply buried mines. This is to be expected as the controlling parameter with large amplitude shock waves would be the air content, and the details of the skeleton structure of the sand would play a small role as the stresses are well beyond the yield point of the sand skeleton. The P_α model reproduced the experimentally measured impulses under conditions of moderate loads, but had difficulty reproducing the peak pressures. The details of the shock propagation are affected by the characteristics of the sand skeleton which are not modeled with the P_α model and the P_α model does not include strain rate effects. The multiphase effective stress model

incorporated compressibility parameters and mechanical properties of dry sand determined from hydrostatic compression, uniaxial strain, and triaxial compression tests, which lent some validity to the results. The numerical results for partially saturated sand looked physically reasonable but there was no comparison with experiment.

These continuum models appear to have modeled the qualitative features correctly, and the quantitative features reasonably well, under conditions of high stress and/or high air content. It is unclear whether these models have the same predictive capability under low/moderate stress and saturated, or nearly saturated, conditions. Under these circumstances, the microscopic structure of the sand skeleton may be important. The micromechanical results, both experimental and numerical, presented at the workshop indicate that the shock propagation characteristics depend strongly on the microstructure. These results were based on low/moderate stress levels - primarily elastic waves. These results may play an important role in sophisticated explosive net designs (multiple shocks, shaped charges) and could play a role in the long time evolution of a single shock where the precursor wave, caused by the rigidity of the sand skeleton, may be important.

A recurring problem facing the experimental community is the accurate measurement of the parameters, and the controllable repeatability of the parameters in a laboratory setting, which may impact the evolution of the shock wave : pore size, grain size, density, water content, air content, packing, compression strength, shear strength, anisotropy, and mineralogy. It is especially difficult to control the degree of saturation; although the limiting cases of dry sand and fully saturated sand (created under conditions of reduced pressure) are attainable. It is nearly impossible to produce a particular saturation level a priori - again pointing out the need for a rapid and accurate means of measuring air content in wet sands. Even if the above set of parameters were measurable, to a reasonable degree of accuracy, it is still not clear what role the above parameters, aside from air content, play in the evolution of the shock wave; yet, the macroscopic equivalents of these parameters are key elements to most computational models and they control the evolution of the stress waves, through the constitutive relations and conservation equations, in a numerical simulation. The macroscopic parameters in a numerical model include yield strength, shear modulus, plastic strain, work-hardening coefficients, longitudinal and transverse sound speeds, bulk modulus, Grüneisen constant, and Bauschinger parameters (controls the unloading characteristics). These parameters are, in turn, related to the physical variables discussed above.

The split-Hopkinson bar, hydrostatic compression, uniaxial strain, and triaxial compression tests are good first steps in this endeavor to measure the physical characteristics of dry and wet sand. Sample preparation for these tests is difficult and repeatability is questionable. The Hopkinson bar test is based on one dimensional analysis but sand grains are large relative to the sample size. Early evolution of the stress-strain relation is not reliable, yet this region is important because the air voids are being compressed during this period. The unloading period is questionable in that it is not clear whether the observed hysteresis phenomena is due to plasticity or failure (loss of water) of the sample. Crushing of the sand sample was observed for the dry tests but not for the wet sand tests.

The integration of microscale phenomena into macroscale phenomena amenable to a continuum model is still in its infancy, although homogenization procedures have worked quite well for ceramics and laminates. The reliability of these procedures rests more on the microscale model chosen than the procedure itself and at this stage it is not apparent which microscale model to employ.

VI. RECOMMENDATIONS

The focus of this workshop was on the constitutive modeling of air and water saturated sandy media as it pertains to the development of accurate, efficient, physics based constitutive models for gassy sediments in and near surf zone environments. The constitutive models control the evolution of the shock wave and improved constitutive models are needed if progress is to be made in performance prediction of mine countermeasure efforts. The present numerical models appear to model the qualitative features reasonably well under conditions of high stress and/or high air content. Detailed comparisons with experiments show some discrepencies with respect to peak stresses, shock rise times, propagation speeds, and mine damage. Errors and/or inadequacies in the constitutive models would manifest themselves in this manner, under the assumption that the conservation equations are being solved correctly.

As noted above, the gas content is the dominant parameter controlling shock attenuation yet there is no accepted method to accurately, and rapidly, measure the gas content in partially saturated sands/soils either in situ or under laboratory controlled conditions. It is our recommendation that ONR take the appropriate steps to address this issue with the following two caveats. (1) Numerical simulations indicate that little additional shock attenuation occurs when the gas content exceeds 5%. If the distributed explosive net, presently being considered for mine clearance in the surf zone, can be designed to provide a large enough pressure load to trigger or disable a buried mine in a partially saturated environment with 5% air, then there is probably no need to know the degree of saturation to high accuracy. (2) It would seem possible to design a double pulse explosive device with the intent that the first pulse would be just large enough (perhaps in the 1 - 2 kilobar range) to collapse the air bubbles in the medium and the second pulse would then propagate nearly unattenuated through a fully saturated sand-water environment. The strength of the first pulse may be a strong function of the gas content as the volume strain required for pressure saturation of the pore air is directly related to the initial air content which varies as a function of depth. In this case, knowledge of the degree of saturation would be vital. In either scenario, the key engineering goal is to design the shape of the shock wave through the design of the explosive. The sand constituents themselves will dictate the shock shape required. The weak link here is knowledge of the sand constituents and their control over the evolution of the shock wave.

A significant effort, entailing significant computer resources, should proceed to define the physical variables, and the parameter range for those variables, that influence the evolution of stress waves in a wet sandy environment under low, moderate, and high loads. This numerical effort should be correlated with an experimental program based on stress-strain

response measurements and shock propagation measurements in a controlled laboratory setting. A convenient way to evaluate the constitutive relations is to do experiments and simulations on dry and fully saturated specimens. This data could be used in estimating parameters for in situ materials associated with a given event. It would appear to be critical to accurately model the stress-strain response of the "dry" sand skeleton. The rigidity of the skeleton determines the velocity of the precursor wave and the elastic limit. For partially saturated sands, the material strength is strongly influenced by the pore pressure response, which is controlled by the volumetric deformation characteristics of the porous skeleton.

We feel there is a need for a more focused effort in micromechanical modeling coupled with well controlled laboratory experiments. For example, propagation of stress waves through individual grains of sand is probably not important; quantification of the contact forces between grains of sand is probably important. If it appears that the microstructure plays a strong role in the shock evolution, then further work on the detailed characterization of the surfzone environment is required in addition to developing continuum, or continuum-like, constitutive relations based on the micromechanics of the surf zone.

Since the ultimate goal is a viable mine countermeasure program, it is important to consider extensions of the research effort suggested above. It is our recommendation that a focused experimental, both in situ and laboratory, and numerical simulation program be developed to investigate both the single pulse and multiple pulse explosive net designs in more detail with the goals being (1), a quantitative description of the shock propagation characteristics as a function of gas content and explosive load for both explosive net designs and (2), a prediction of performance capability for both distributed explosive net designs. The following issues need to be addressed : experimental measurement of shock attenuation for air content exceeding 5% and comparison with computational results; experimental data for shock propagation characteristics in a fully saturated sand environment as a function of range and comparison with computational results; numerical simulations detailing the strength and duration of the loads required for pressure saturation of the pore air as a function of air content and range with experimental verification; and, numerical simulations of the loads and timings required for the double pulse explosive net design with experimental verification.

In summary, our recommendations to NRL and ONR are :

- make a concerted effort to develop techniques (both laboratory and in situ) to accurately and rapidly measure air content in partially saturated sandy media,
- develop a detailed experimental and computational program to define, measure, and calculate the physical variables controlling shock evolution in a wet, sandy environment,
- determine which micromechanical properties are important to a physics based constitutive model and develop the means to incorporate those properties into continuum numerical (hydrodynamic) models,

- enlarge the scope of distributed explosive net designs to include multiple shocks and shaped charges with computational and experimental support.

Several of these efforts may already have taken place or are now taking place within the ONR community, but this was not apparent at the workshop.

ACKNOWLEDGEMENTS

The workshop chairs gratefully acknowledge the financial support of Dr. B. B. Rath, Associate Director of Research, Code 6000 and Dr. E. O. Hartwig, Associate Director of Research, Code 7000. In addition, we thank Joyce DelGiudice for serving as conference secretary in her usual efficient and pleasant manner.

ATTENDEES

Dr. Roshdy Barsoum
Structural Mechanics Division
Code 334
Office of Naval Research
800 N. Quincy Street
Ballston Towers #1
Arlington, VA 22217

Dr. John Bergin
Code 3220M
Office of Naval Research
800 N. Quincy Street
Ballston Towers #1
Arlington, VA 22217

Dr. L. Dale Bibee
Code 7432
NRL-SCC
Stennis Space Center, MS 39529

Scott E. Blouin, Vice-President
Applied Research Associates, Inc.
120A Waterman Road
South Royalton, VT 05068

Dr. Douglas Bruder
Program Manager, Shock Physics Directorate
HQ DNA/SPSD
6801 Telegraph Road
Alexandria, VA 22310-3398

Dr. Howard Chen
Code 40E
NSWC, Dahlgren Division
Indian Head Detachment
10901 New Hampshire Avenue
Silver Spring, MD 20903-5640

Daniel E. Chitty, PE
Applied Research Associates, Inc.
120A Waterman Road
South Royalton, VT 05068

Dr. Carl T. Dyka
Code 6386
NRL
4555 Overlook Dr. SW
Washington, DC 20375

Dr. Mark H. Emery
Code 6440
NRL
4555 Overlook Dr. SW
Washington, DC 20375

Dr. Russell H. England
Titan Research and Technology
9410 Topango Canyon Road
Chatsworth, CA 91311-5771

Dr. Dan Flippen
Code 6386
NRL
4555 Overlook Dr. SW
Washington, DC 20375

Jean Goertner
Code R14
NSWC, Dahlgren Division
Indian Head Detachment
10901 New Hampshire Avenue
Silver Spring, MD 20903-5640

Dr. Raafat H. Guirguis
Code 9210
NSWC, Dahlgren Division
Indian Head Detachment
10901 New Hampshire Avenue
Silver Spring, MD 20903-5640

Dr. William H. Holt
Code G22
NSWC
Dahlgren Division
Dahlgren, VA 22448-5100

Dr. Joseph H. Kravitz
Code 32466
Office of Naval Research
800 N. Quincy Street
Ballston Towers #1
Arlington, VA 22217

Hans Mair
Code 460
NSWC, Dahlgren Division
Indian Head Detachment
10901 New Hampshire Avenue
Silver Spring, MD 20903-5640

Dr. B. Edward McDonald
Code 7104
Naval Research Laboratory
4555 Overlook Dr. SW
Washington, DC 20375

Dr. Ras B. Pandey
Dept. of Physics & Astronomy
Univ. of Southern Mississippi
Box 5046
Hattiesburg, MS 39406

Prof. Dunja Peric'
Dept. of Civil Engineering
University of Colorado/Boulder
Boulder, CO 80217

Dr. Quan Qi
Dept. of Mechanical Engineering
University of Colorado - Boulder
Boulder, CO 80309

Prof. Arun Shukla
Department of Mechanical Engineering
University of Rhode Island
Kingston, RI 02881

Dr. Doug Tasker
Code 920
NSWC, Dahlgren Division
Indian Head Detachment
10901 New Hampshire Avenue
Silver Spring, MD 20903-5640

Dr. Phil Valent
Code 7401
NRL-SCC
Stennis Space Center, MS 39529

Dr. William Wilson
Code 920
NSWC, Dahlgren Division
Indian Head Detachment
10901 New Hampshire Avenue
Silver Spring, MD 20903-5640

Dr. Joseph S. Zelasko
CEWES-SD
3909 Halls Ferry Road
Vicksburg, MS 39180

Dr. Frank Zerilli
Code 920
NSWC, Dahlgren Division
Indian Head Detachment
10901 New Hampshire Avenue
Silver Spring, MD 20903-5640

Dr. Duan Z. Zhang
Dept. of Mechanical Engineering
3400 Charles Street
Johns Hopkins University
Baltimore, MD 21218